Cognitive load in science and introducing integrated instructions

Objectives

List and combine the central components of cognitive load
Identify and examine exemplar strategies to maxinimse the chance of new knowledge entering the long term memory.

CCF LINK Section 2 How pupils learn. Learn that:

Working memory is where information that is being actively processed is held, but its capacity is limited and can be overloaded.
Long-term memory can be considered as a store of knowledge that changes as pupils learn by integrating new ideas with existing knowledge.
Worked examples that take pupils through each step of a new process are also likely to support pupils to learn.

Learn how to

Discussing and analysing with expert colleagues how to reduce distractions that take attention away from what is being taught (e.g. keeping the complexity of a task to a minimum, so that attention is focused on the content). And - following expert input - by taking opportunities to practise, receive feedback and improve at:
Breaking complex material into smaller steps (e.g. using partially completed examples to focus pupils on the specific steps).

Acknowledgements

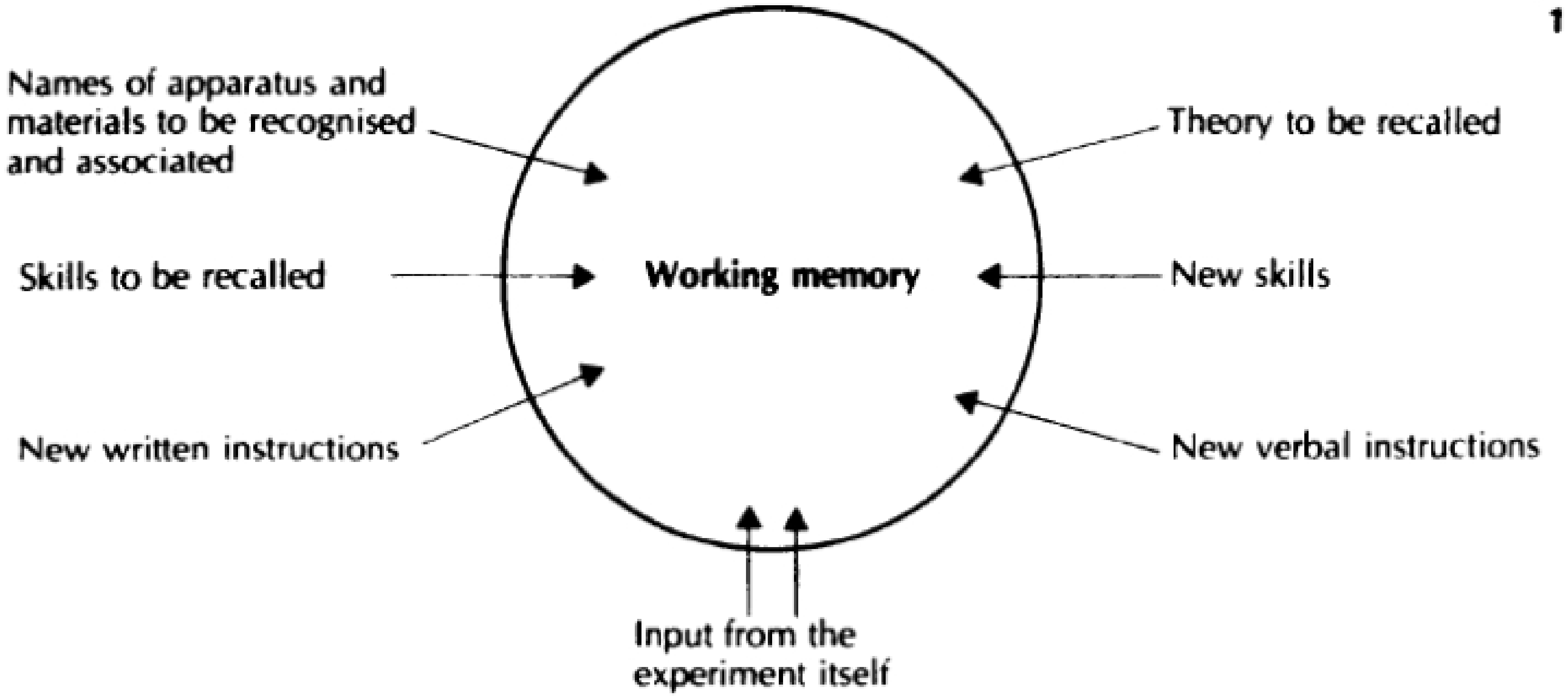
RSC Chemical Education Research Group Teacher-Researcher Fellowship Scheme 2018

David Patterson under the supervison of Suzanne Fergus, Michael Seery.

Staff and students at Aldenham School

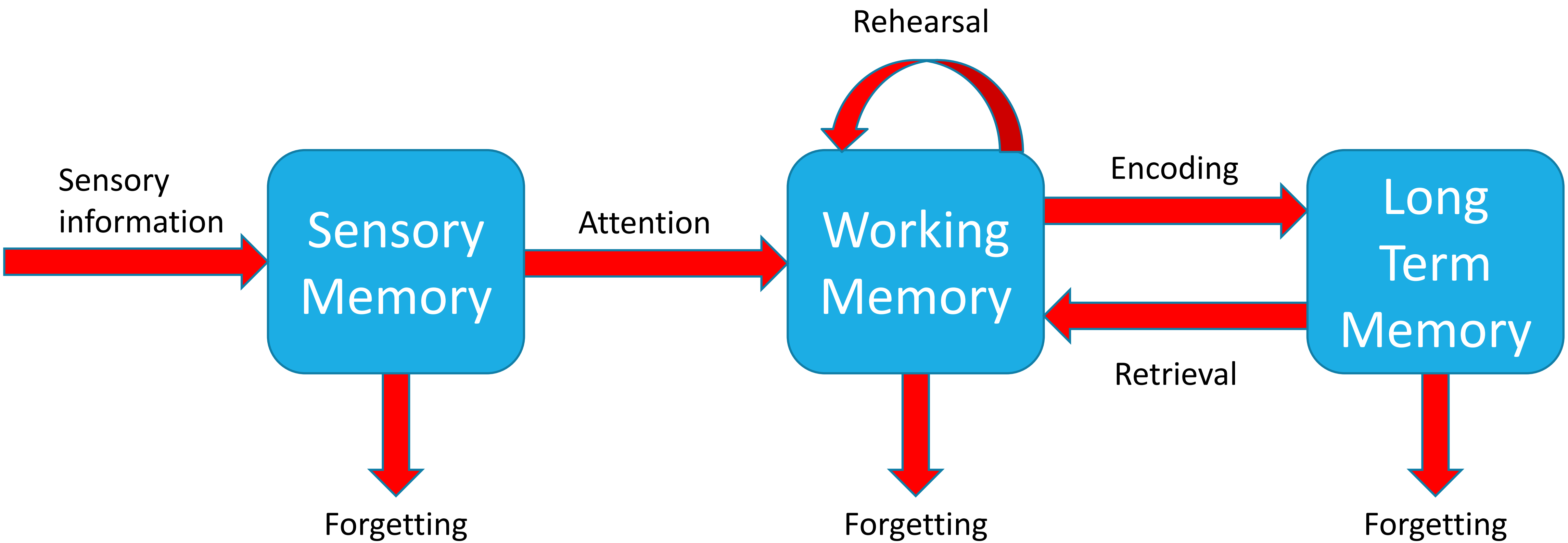
Steve Jones and Bob Worley, CLEAPSS

Practical work – a hard ask for students



Clark, R., Nguyen, F. & Sweller, J. (2006) Efficiency in Learning: Evidence-Based Guidelines to Manage Cognitive Load. John Wiley & Sons.

Working and Long Term Memory



Atkinson–Shiffrin memory model (1968) / Baddeley (1992) for WM rather than STM

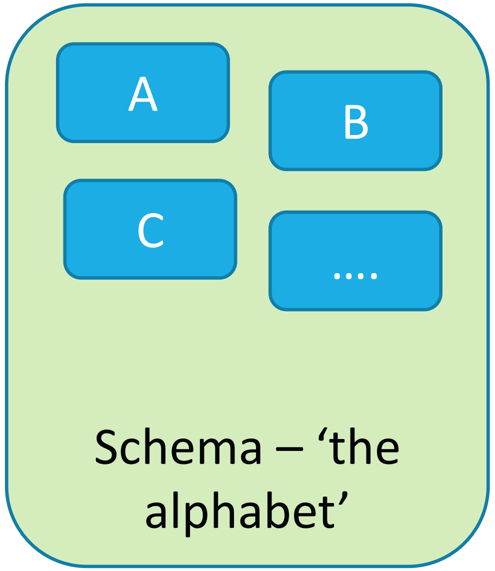
Working Memory

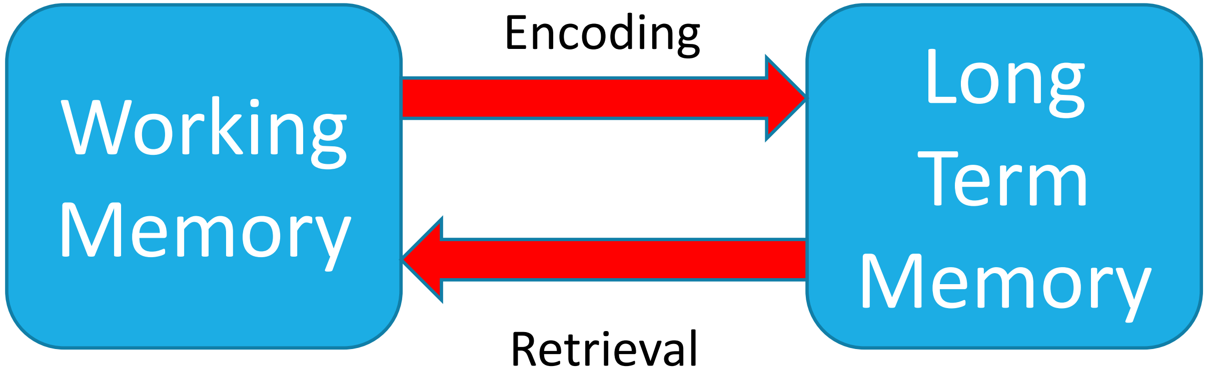
Where you ‘consciously think’

Limited capacity

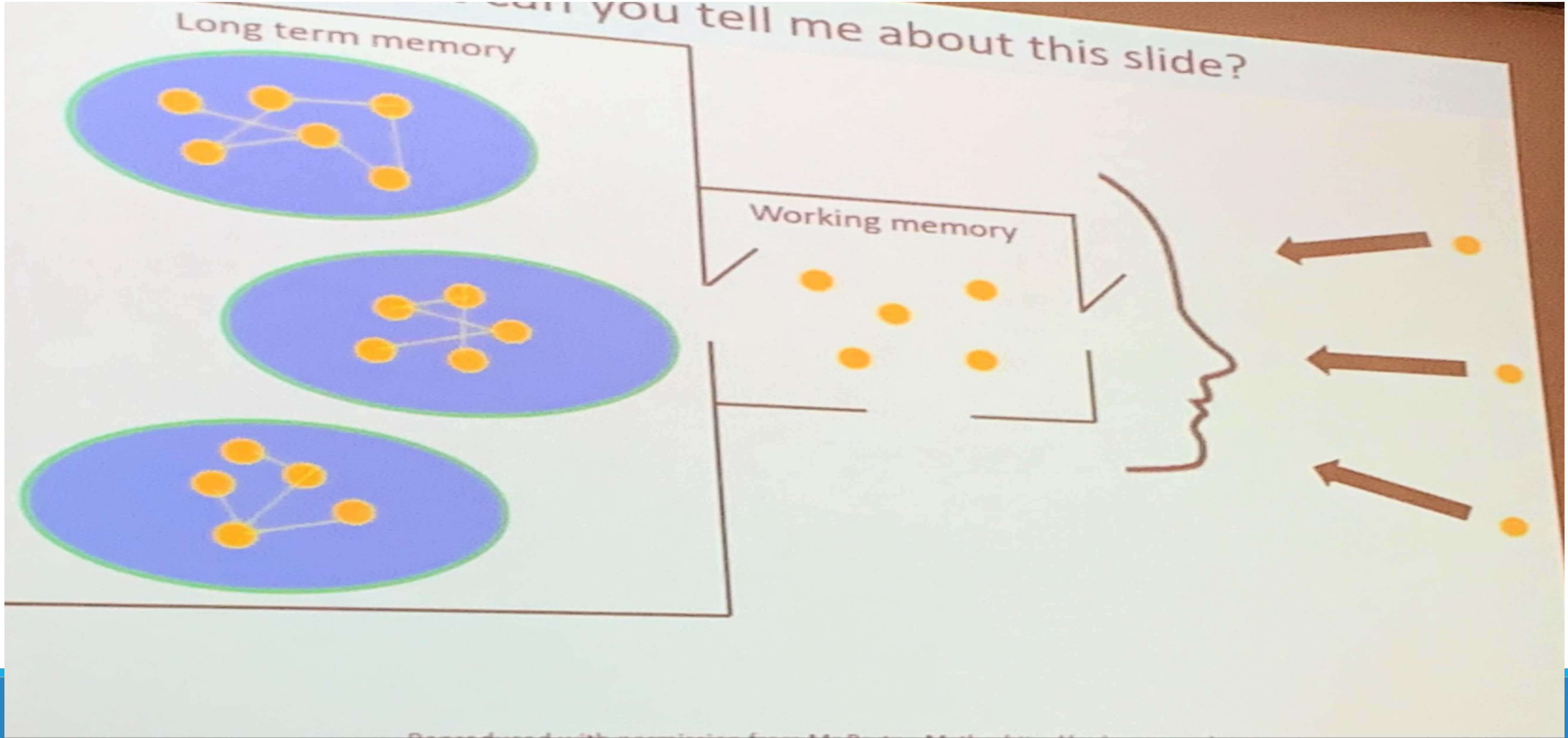
If it is overloaded, task completion/learning is impeded

Long-term Memory: Schema

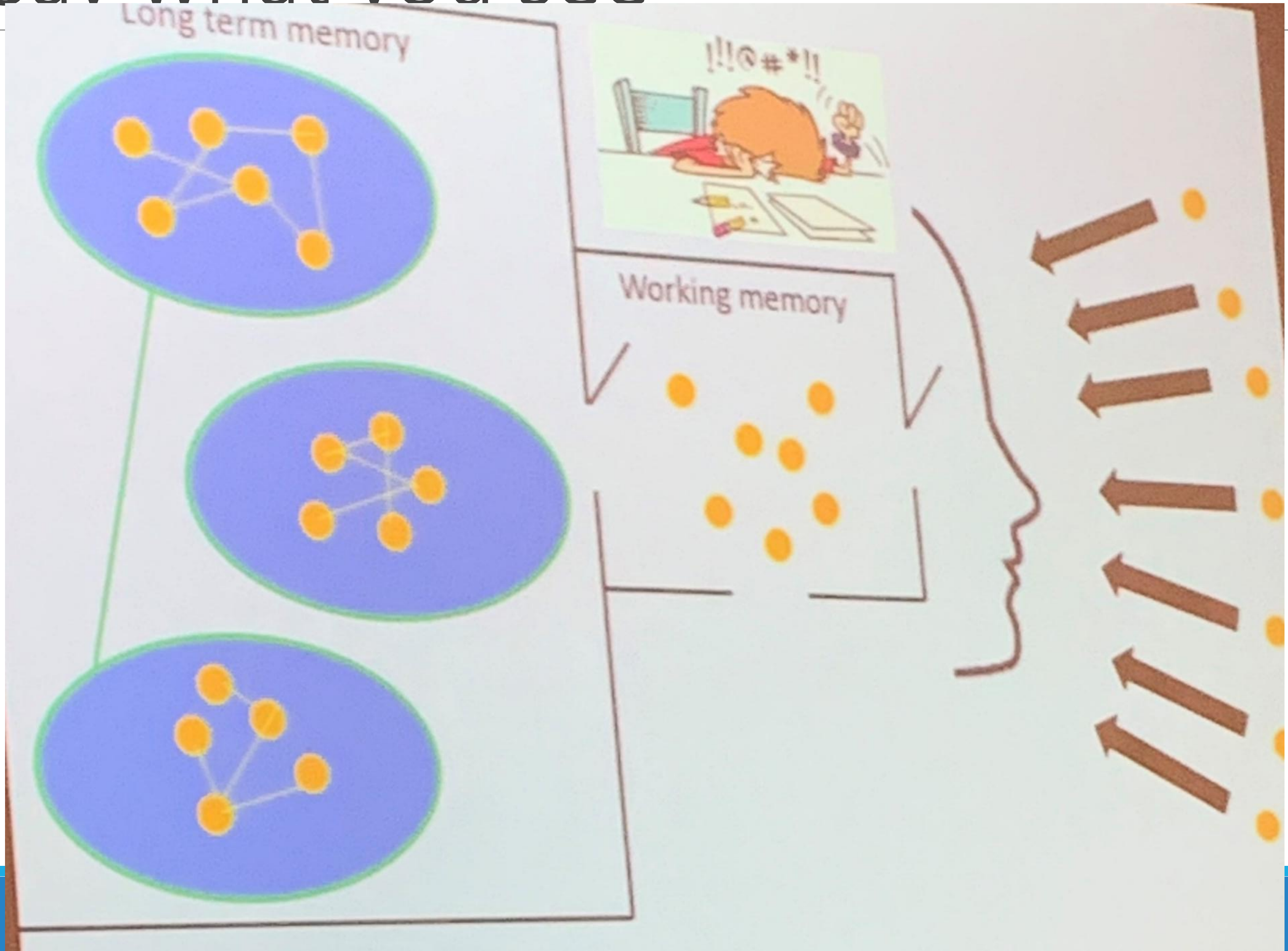




Say what you see



Say what you see

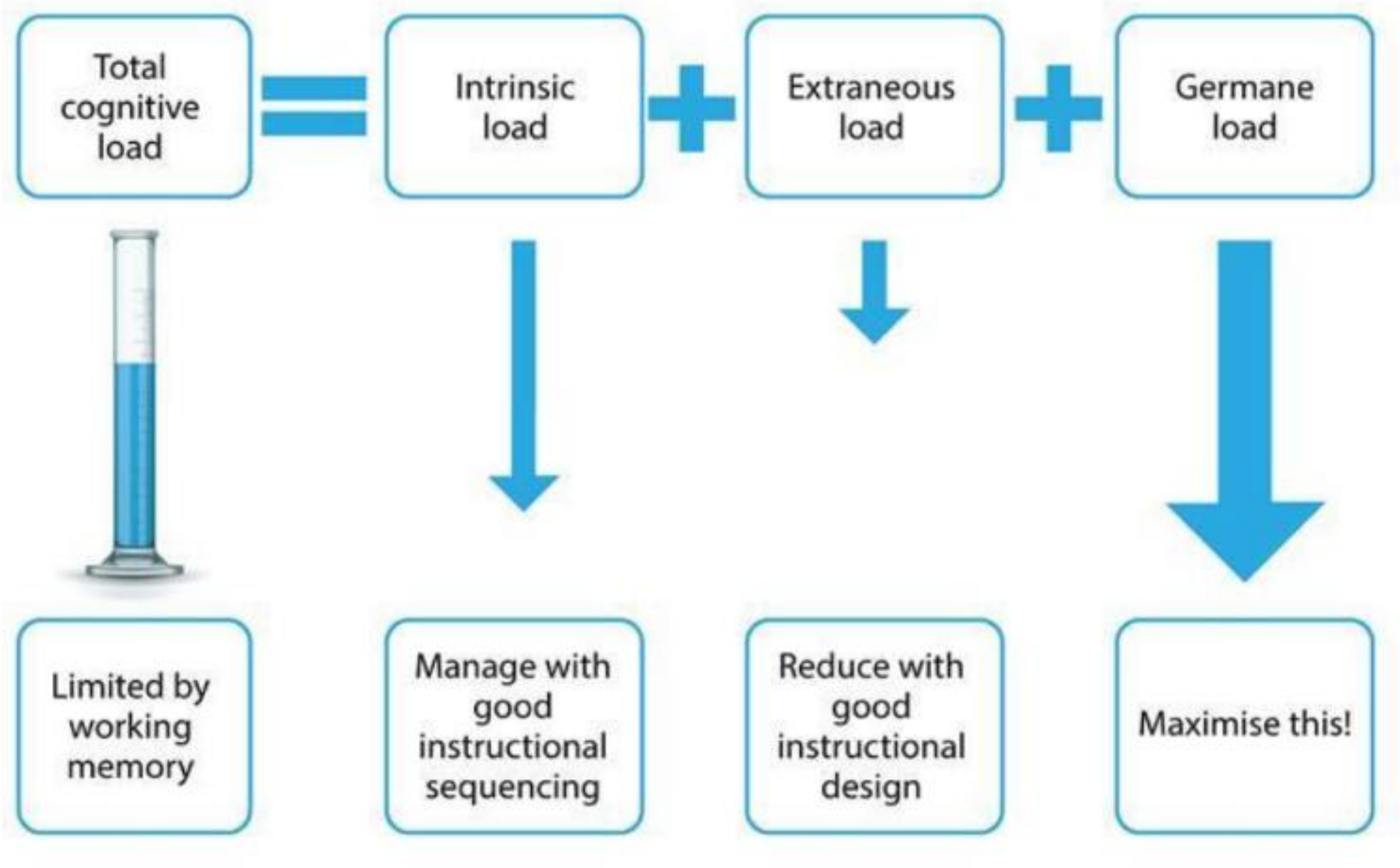


Cognitive Load Theory (CLT)

What is happening in the Working Memory? Three types of load…

Intrinsic	• complexity of concepts • inter-relatedness of ideas
Extraneous	• complexity of the instructional materials • external influences
Germane	• building the mental models (schema) about the concepts

Cognitive Load Theory (CLT)



Greer, D.L., *et al*, Cognitive theory of multimedia learning..., *Journal of Education*, 2013, 193(2), 41-50
https://www.researchgate.net/publication/269112838

Exemplar metacognitive strategies which can reduce cognitive load

Technique	Description
1. Elaborative interrogation	Generating an explanation for why an explicitly stated fact or concept is true
2. Self-explanation	Explaining how new information is related to known information, or explaining steps taken during problem solving
3. Summarization	Writing summaries (of various lengths) of to-be-learned texts
4. Highlighting/underlining	Marking potentially important portions of to-be-learned materials while reading
5. Keyword mnemonic	Using keywords and mental imagery to associate verbal materials
6. Imagery for text	Attempting to form mental images of text materials while reading or listening
7. Rereading	Restudying text material again after an initial reading
8. Practice testing	Self-testing or taking practice tests over to-be-learned material
9. Distributed practice	Implementing a schedule of practice that spreads out study activities over time
10. Interleaved practice	Implementing a schedule of practice that mixes different kinds of problems, or a schedule of study that mixes different kinds of material, within a single study session

Note. See text for a detailed description of each learning technique and relevant examples of their use.

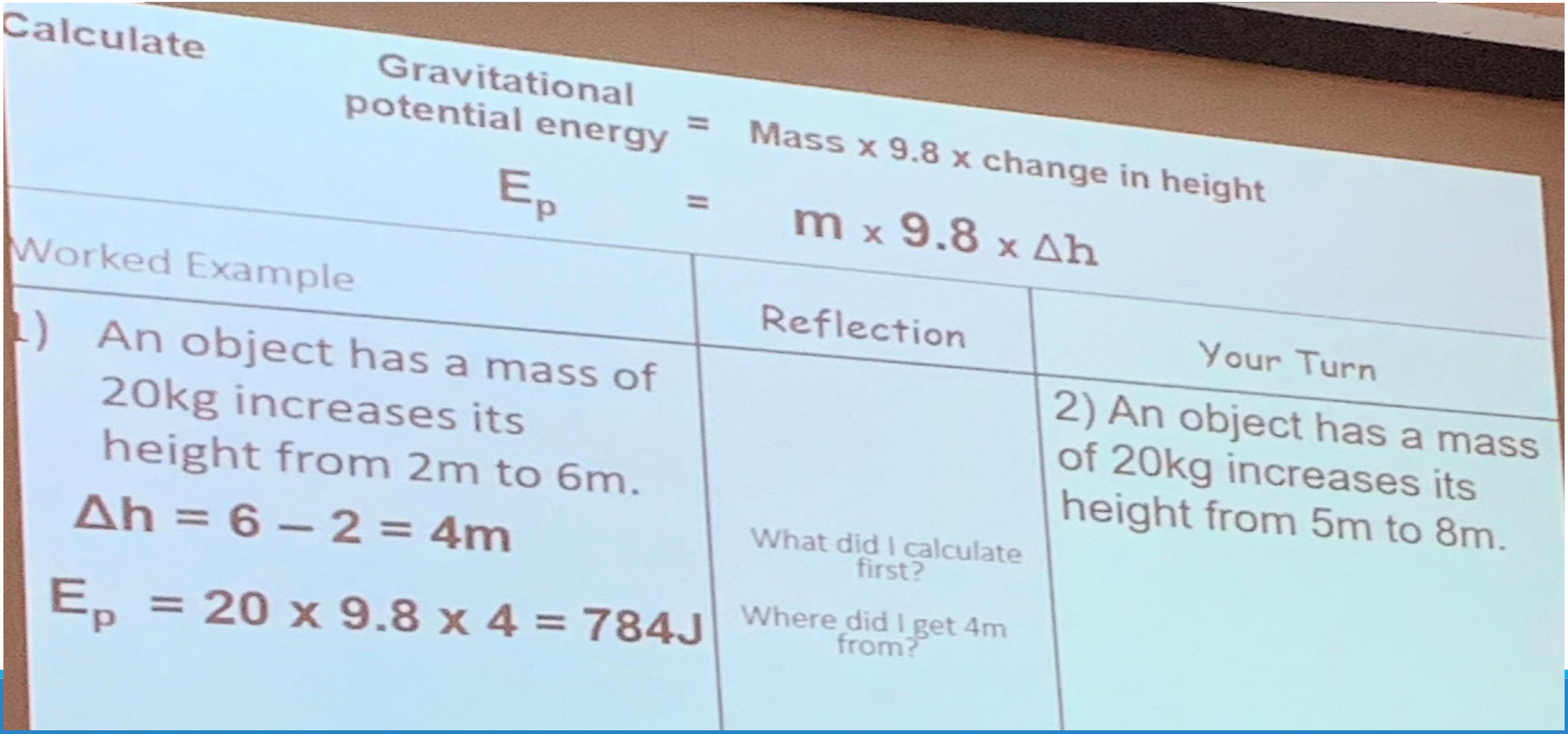
Donker, A. S., de Boer, H., Kostons, D., Dignath van Ewijk, C. C., & van der Werf, M. P. C. (2014) Effectiveness of learning strategy instruction on academic performance: A meta-analysis. *Educational Research Review*, *11*, 1–26. https://doi.org/10.1016/j.edurev.2013.11.002. (Table taken from p6)

How do you develop germane load?

CONSIDER LEARNERS PRIOR KNOWLEDGE!

Novice students	Gradually remove support →	Expert students
Teachers model rationale for each step		Students self explain rationale for each step
Teacher explain how topics build and link to each other starter last lesson last topic last year		Students build own concept maps that link topics together

Showing the rationale (Sweller et all 1988)



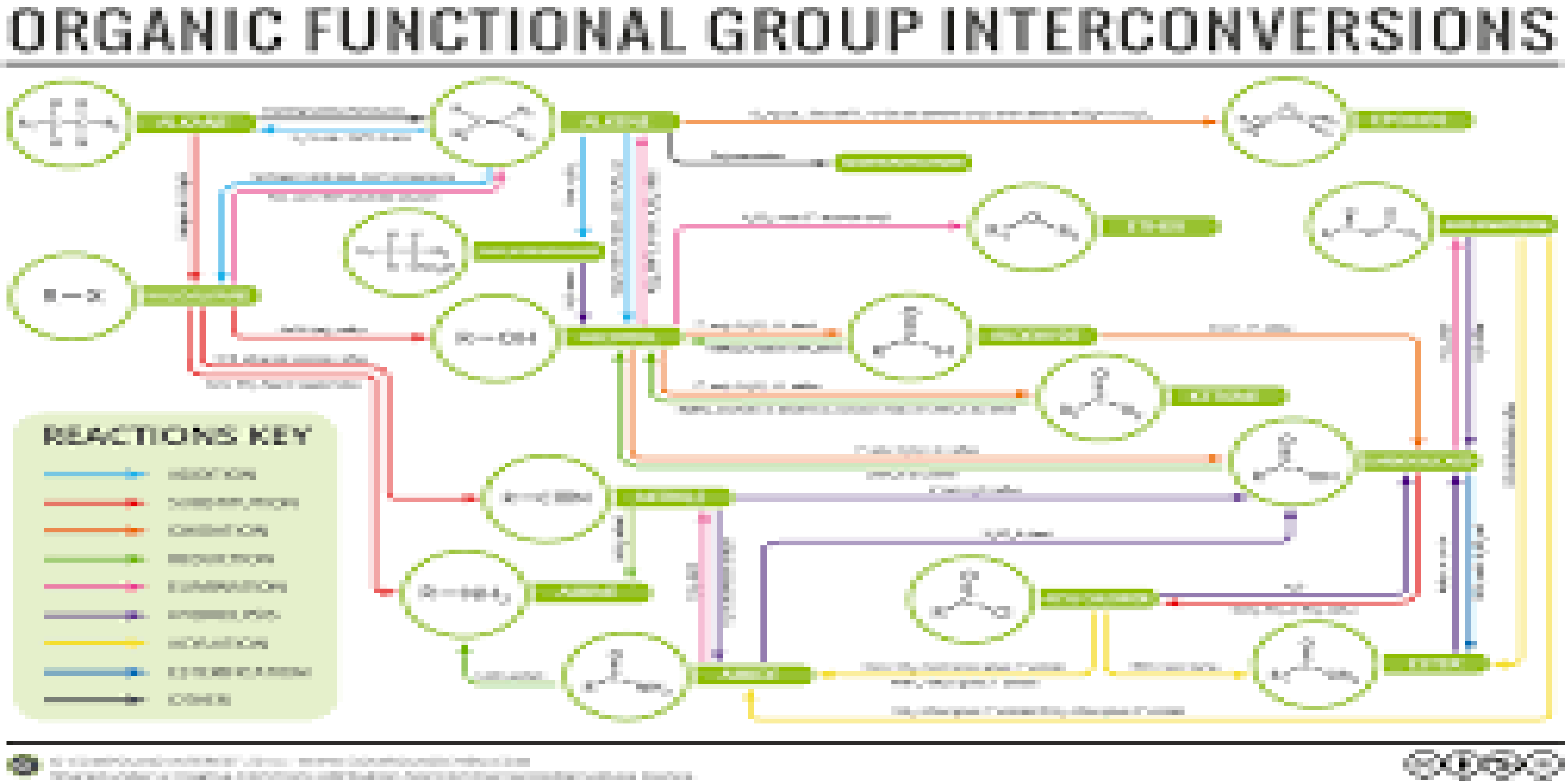
Calculate

Gravitational potential energy = Mass x 9.8 x change in height

$E_p = m \times 9.8 \times \Delta h$

Worked Example	Reflection	Your Turn
1) An object has a mass of 20kg increases its height from 2m to 6m. $\Delta h = 6 - 2 = 4m$ $E_p = 20 \times 9.8 \times 4 = 784J$	What did I calculate first? Where did I get 4m from?	2) An object has a mass of 20kg increases its height from 5m to 8m.

Modelling concept maps



How do you reduce extraneous load

technique	Description	Impact
Worked example	Replaces conventional problems and crutches with worked examples.	Reduces extraneous load by exemplifying key steps to problems.
Completion effect (faded examples)	Replace conventional problems with worked examples where certain steps are missing	Reduces extraneous load by gradually giving different parts of the problem allowing time to embed each step
Split attention effect		
Modality effect	Remove excess text from slides use visual cues with narration to explain concepts	Reduces extraneous load as the multimodal presentation visual and auditory processors
Goal free effect	Replace conventional problems with goal free problems which provide students with non specific goal	Reduces extraneous load caused by relating a problem to a specific goal
Redundancy effect	Replace multiple sources of information and distractors	Reduces extraneous load caused by unnecessarily processing redundant information

Worked examples problem pairs

Examples-Problem pairs in worksheets:

Potential Difference = Current x resistance

1) A cell has a current of 4A and a resistance of 2Ω. Calculate the potential difference.

V = current x resistance = 4 x 2 = 8 V

2) A cell has a current of 6A and a resistance of 1.5Ω. Calculate the potential difference

3) A cell has a potential difference of 4V and a resistance of 2Ω. Calculate the current

Current = V ÷ R = 4 ÷ 2 = 2 A

4) A cell has a resistance of 6Ω and a potential difference of 1.5V. Calculate the curren

5) A cell has a potential difference of 3V and a current of 12A. Calculate the resistanc

R = V ÷ I = 3 ÷ 12 = 0.25 Ω

6) A cell has a current of 3A and a potential difference of 12V. Calculate the resistan

Minimally different worked examples

Minimally Different Examples

1. An object moves **10m** in a time of **2s**. Calculate the speed.

   $10 \div 2 = 5$ m/s

2. In a time of **10s** An object moves **2m**. Calculate the speed.

   $2 \div 10 = 0.2$ m/s

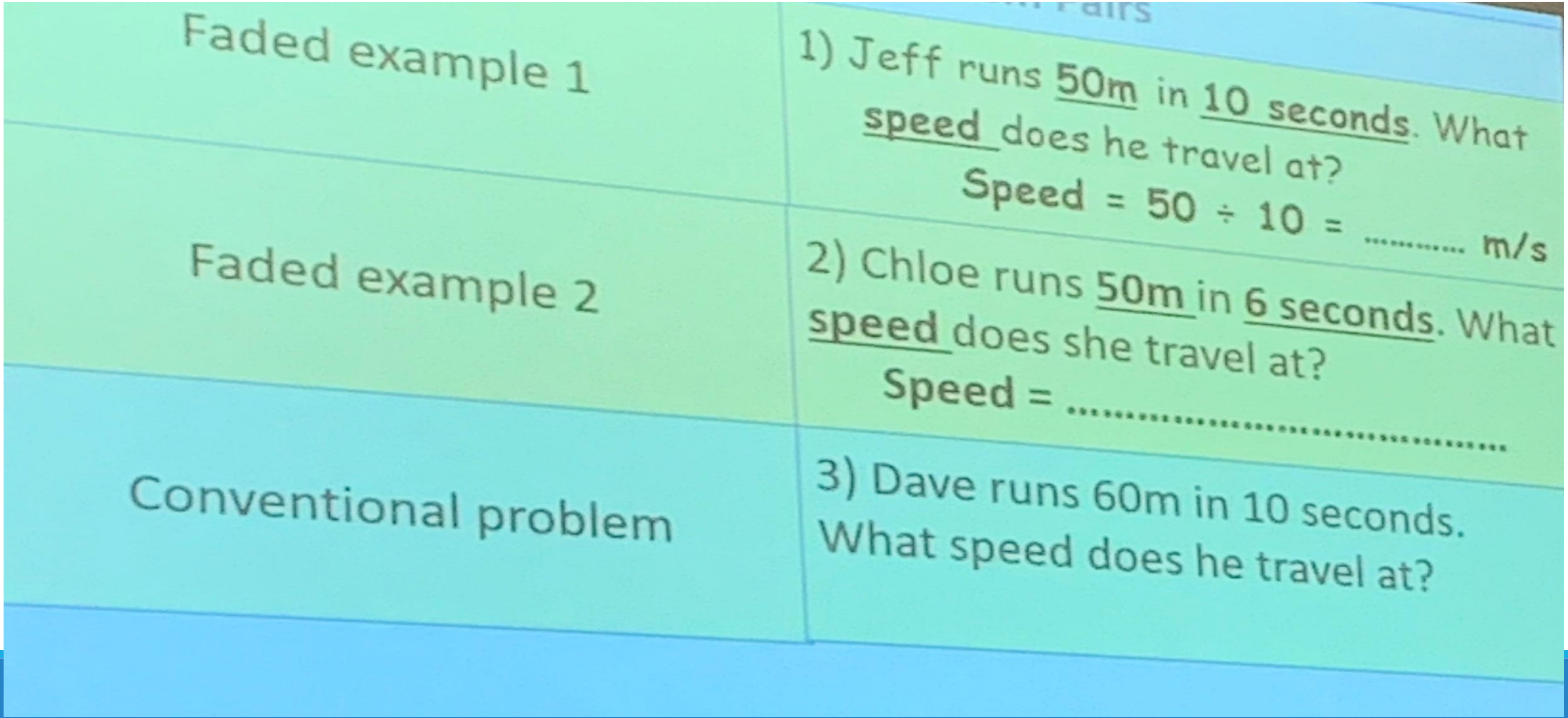
3. An object moves at **10m/s** in a time of **2s**. Calculate the distance travelled.

   $10 \times 2 = 20$ m

4. An object for **10s** is moving at a at a speed of **2m/s**. Calculate the distance travelled.

5. An object is travelling for **4** minutes at a speed of **2m/s**. Calculate the distance travelled.

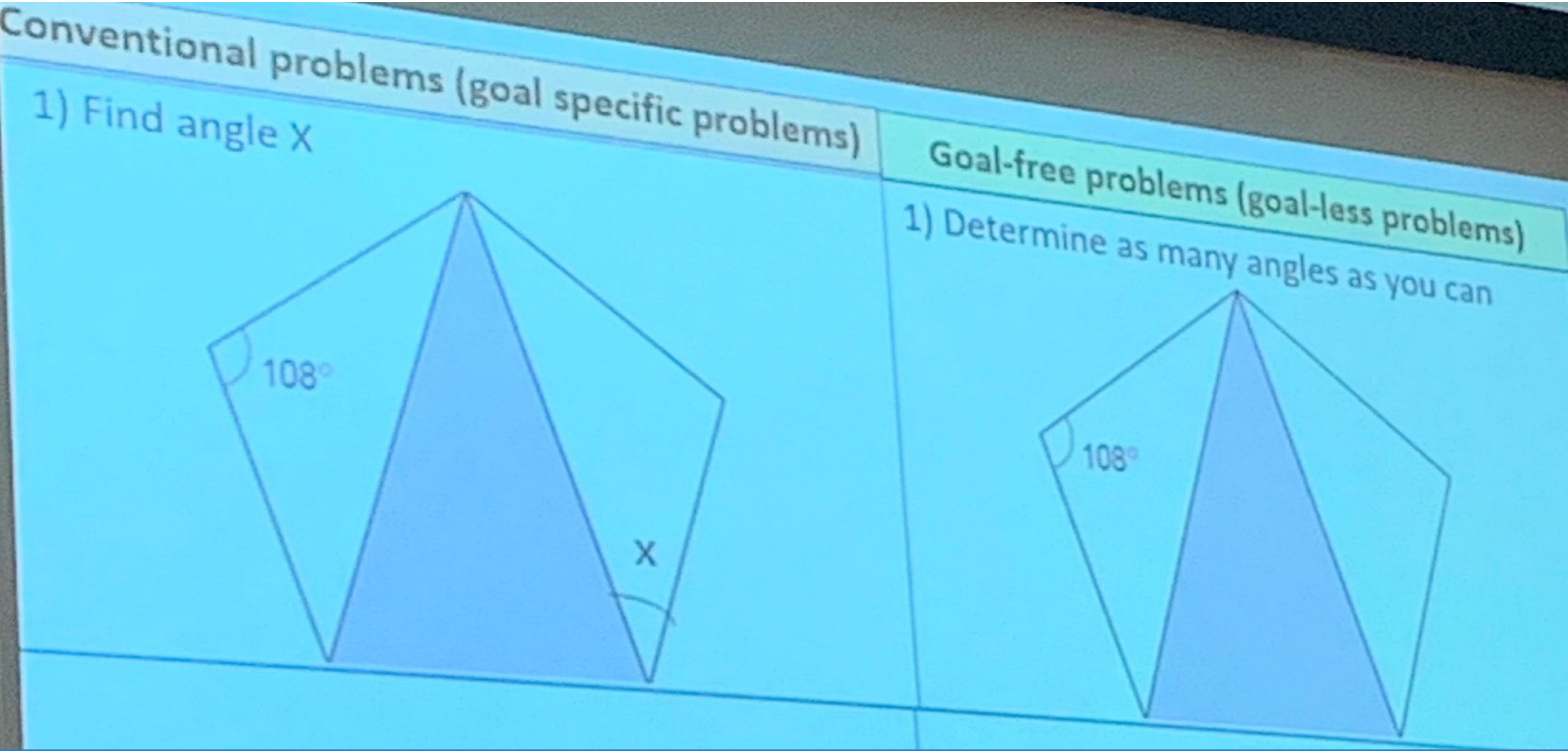
Faded examples



Faded example 1	1) Jeff runs 50m in 10 seconds. What speed does he travel at? Speed = 50 ÷ 10 = ………… m/s
Faded example 2	2) Chloe runs 50m in 6 seconds. What speed does she travel at? Speed = …………………………………………
Conventional problem	3) Dave runs 60m in 10 seconds. What speed does he travel at?

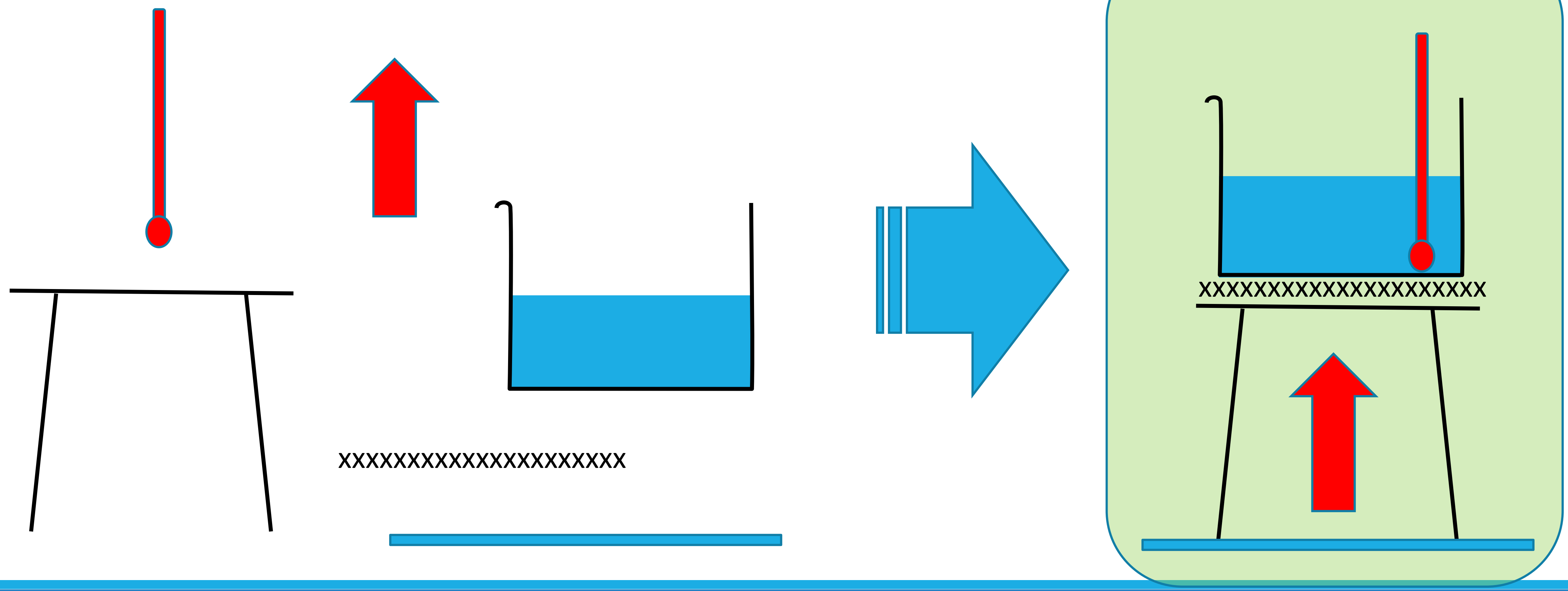
Q1) Worked example	1. An object has a kinetic energy of <u>2000J</u> and a velocity of <u>2m/s</u>. Calculate its <u>mass</u>. $m = E_k \div (0.5 \times v^2)$ $m = 2000 \div (0.5 \times 2^2)$ $m = 2000 \div (2)$ $= 1000$ kg
) Faded example (last step to complete)	2. An object has a kinetic energy of <u>6000J</u> and a velocity of <u>12m/s</u>. Calculate its mass. $m = E_k \div (0.5 \times v^2)$ $m = 6000 \div (0.5 \times 12^2)$ $m = 6000 \div (72)$ = ...
) Faded example ast two steps to complete)	3. An object has a kinetic energy of <u>3kJ</u> and a velocity of <u>6m/s</u>. Calculate its <u>mass.</u> $m = E_k \div (0.5 \times v^2)$ 3kJ x 1000 = 3000J $m = 3000 \div (0.5 \times 12^2)$ m = ... ÷ (.........................) = ...
Q4) Conventional problem	4. An object has a kinetic energy of 4kJ and a velocity of 2m/s. Calculate its mass.

Goal free effect



Reducing instrinsic load
Long term Memory: A science schema

Heat 100 cm^3 of water to 50°C

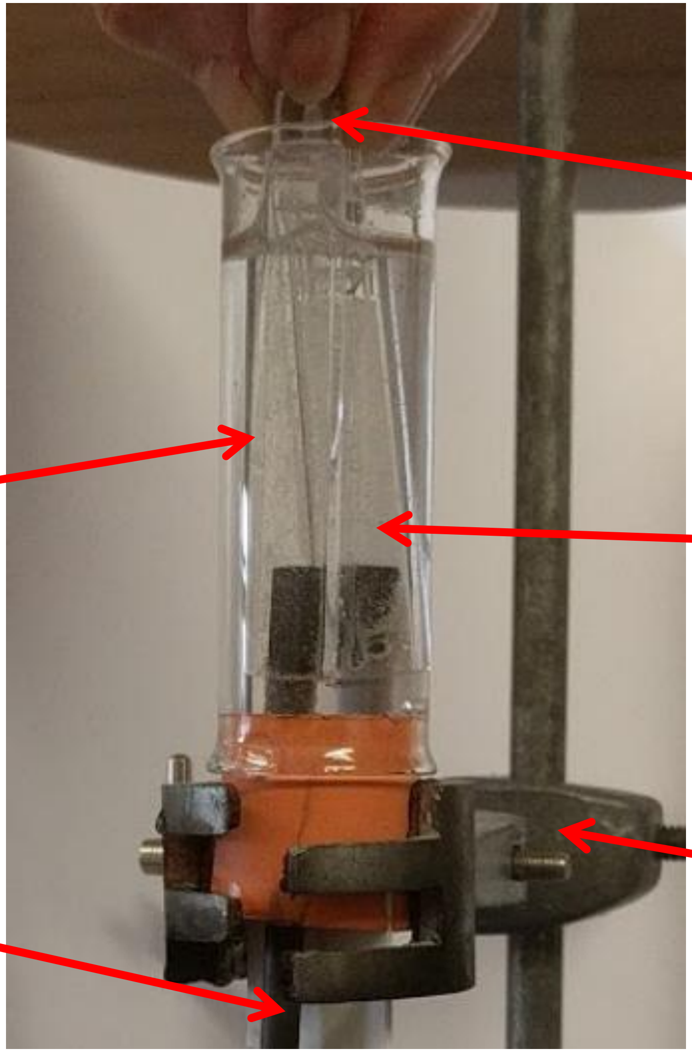


Example: Titration

An intrinsically complex activity

- New equipment
- Recalling prior knowledge
- Making and understanding observations
- Accurate measurement
- Calculation

Extraneous load - electrolysis



Collecting enough gas

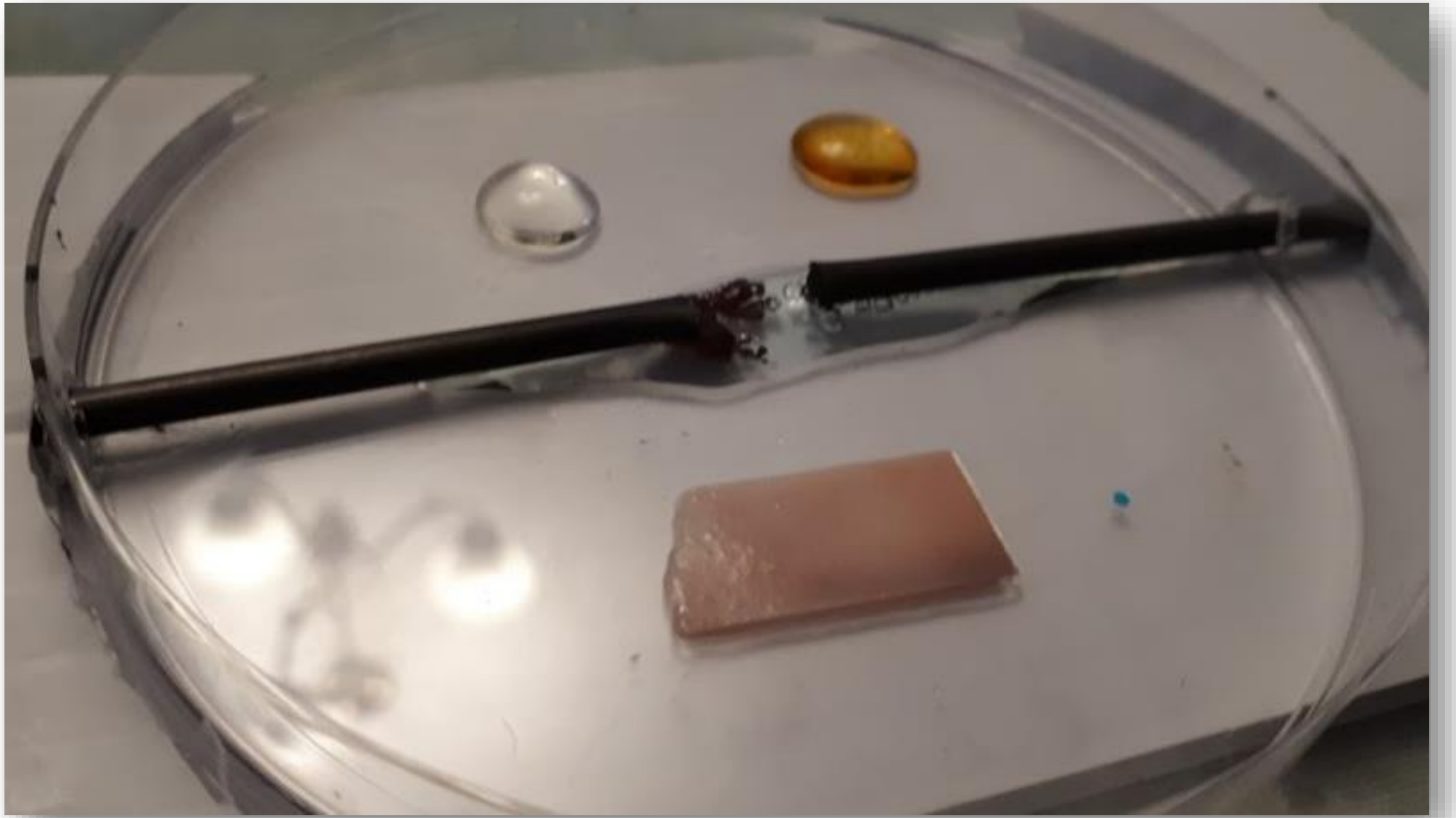
Spillages in setting up the test tubes

Getting the test tubes filled

Connecting power pack and getting it working

Getting the boss and clamp right

Simplifying equipment



Split attention – a demonstration

Time how long it take you to:

Write out all the numbers from 1 to 26 in order, left to right.

---THEN---

Write out all the letters from A to Z in order, left to right.

Make a note of how long that took.

Split attention – a demonstration

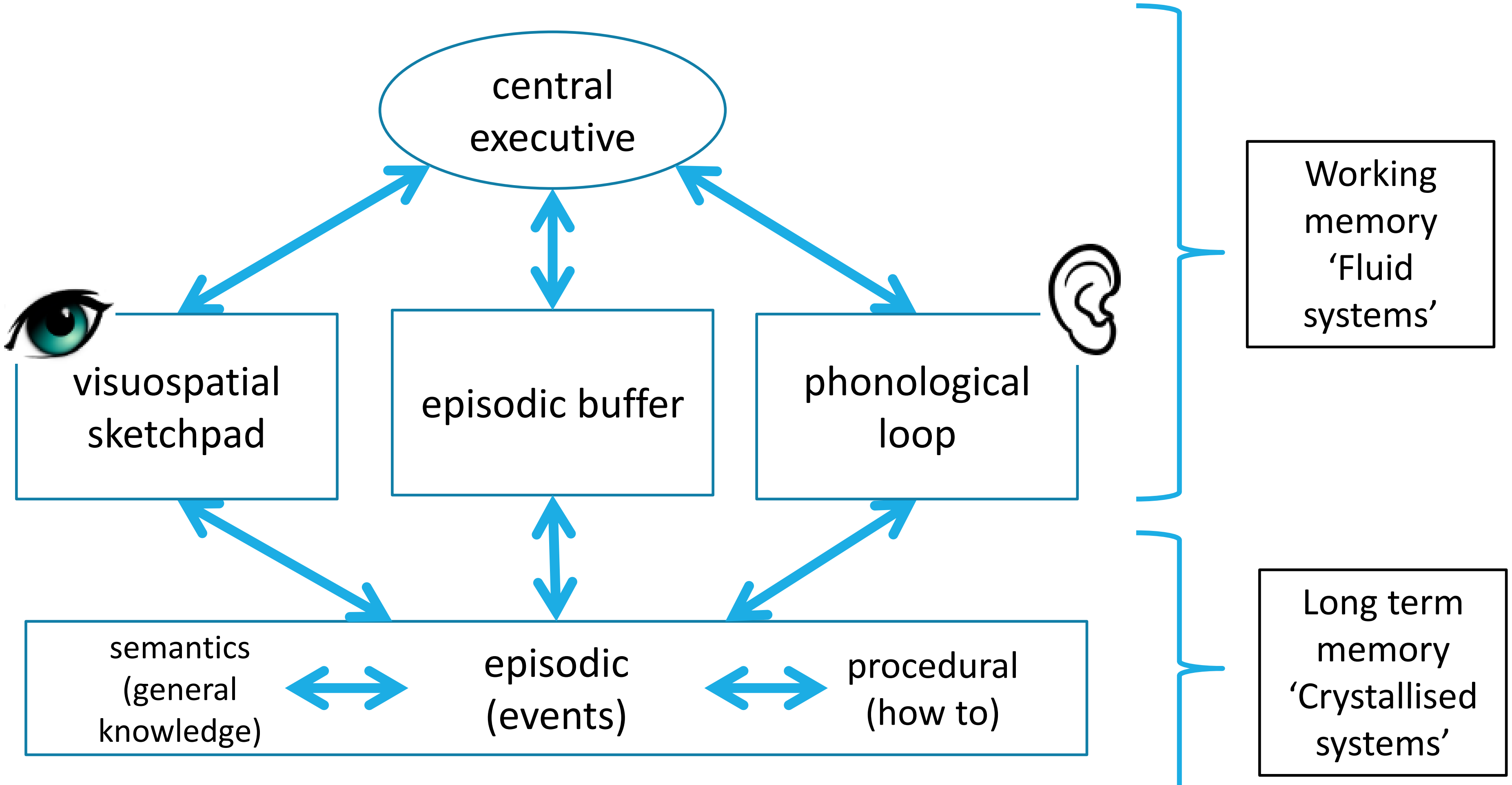
Without looking at your previous work…

Time how long it takes you to:

Write out A1, B2, C3 through to Z26, in order, left to right.

Compare with your previous time.

A model of memory



Baddeley. A., The episodic buffer: a new component of working memory?, *Trends in Cognitive Science,* 2000, **4**(11), 417-23 - http://www.sciencedirect.com/science/article/pii/S1364661300015382

Extraneous load – the split-attention effect

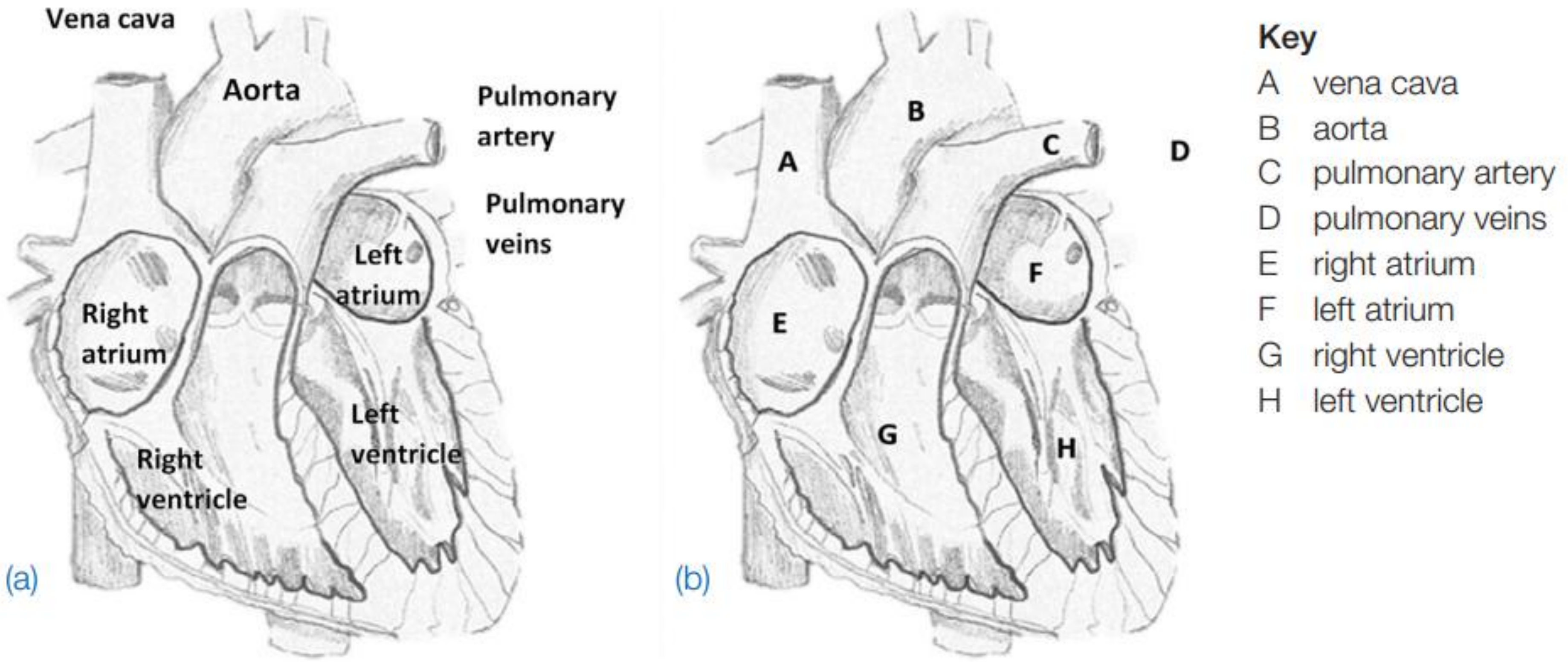


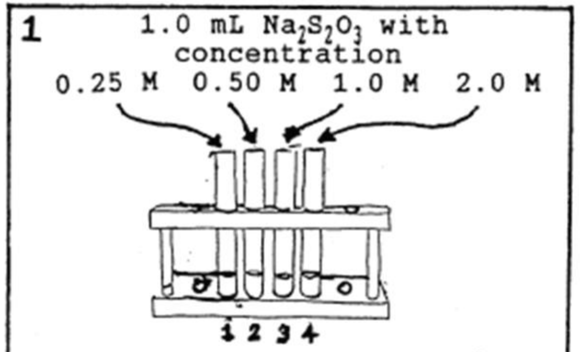
Figure 2 The spatial contiguity principle: (a) reducing extraneous load by integrating labels with visualisation; (b) extraneous load is increased when labels are not integrated with visualisation

Rebecca Torrance Jenkins, *Using educational neuroscience and psychology to teach science Part 1*. **SSR December 2017**

Integrated Instructions – Deschri *et al*

1. Obtain four clean, dry test tubes. Pour 1.0 mL samples of sodium thiosulfate solution ($Na_2S_2O_3$) into the tubes as follows:

   Tube 1 0.25 M $Na_2S_2O_3$
   Tube 2 0.50 M $Na_2S_2O_3$
   Tube 3 1.0 M $Na_2S_2O_3$
   Tube 4 2.0 M $Na_2S_2O_3$



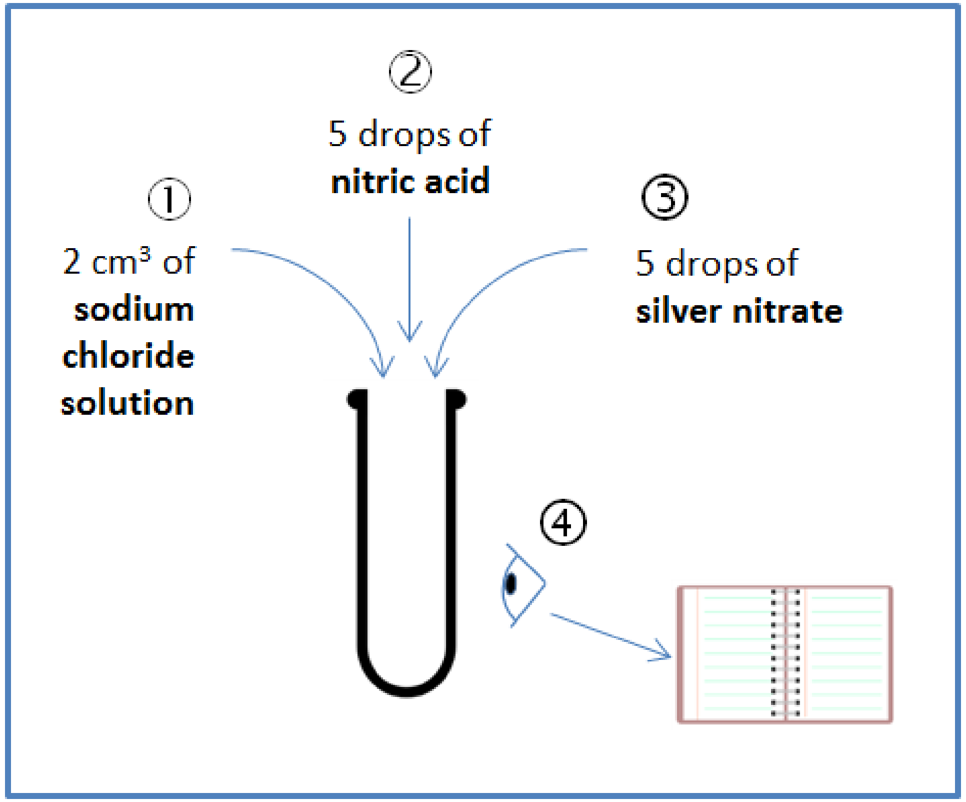
Obtain four clean, dry test tubes. Pour 1.0 mL samples of sodium thiosulfate solution ($Na_2S_2O_3$) into the tubes as follows:

Tube 1 0.25 M $Na_2S_2O_3$
Tube 2 0.50 M $Na_2S_2O_3$
Tube 3 1.0 M $Na_2S_2O_3$
Tube 4 2.0 M $Na_2S_2O_3$

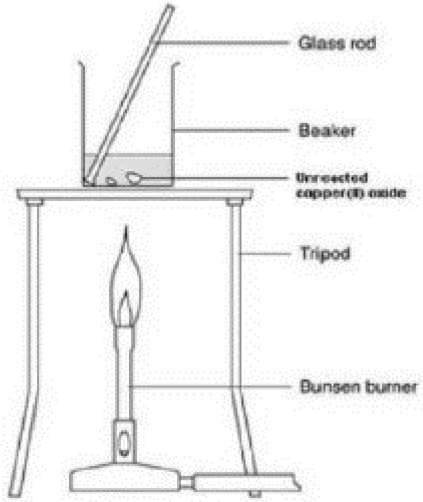
Deschri *et al* (1997), J Res Sci Teach, 34(9), 891-904: Effect of a Laboratory Manual Design Incorporating Visual Information-Processing Aids on Student Learning and Attitudes

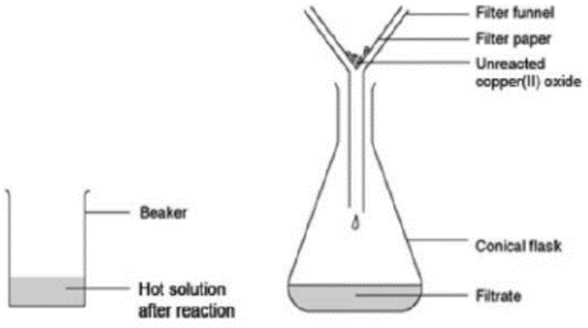
Integrated Instructions

1. Add 2 cm^3 of 0.2 M sodium chloride solution to a test tube.
2. Add 5 drops of 0.5 M nitric acid to the same test tube.
3. Add 5 drops of 0.1 M silver nitrate solution to the same test tube.
4. Make and record your observations.



Split attention in practical work



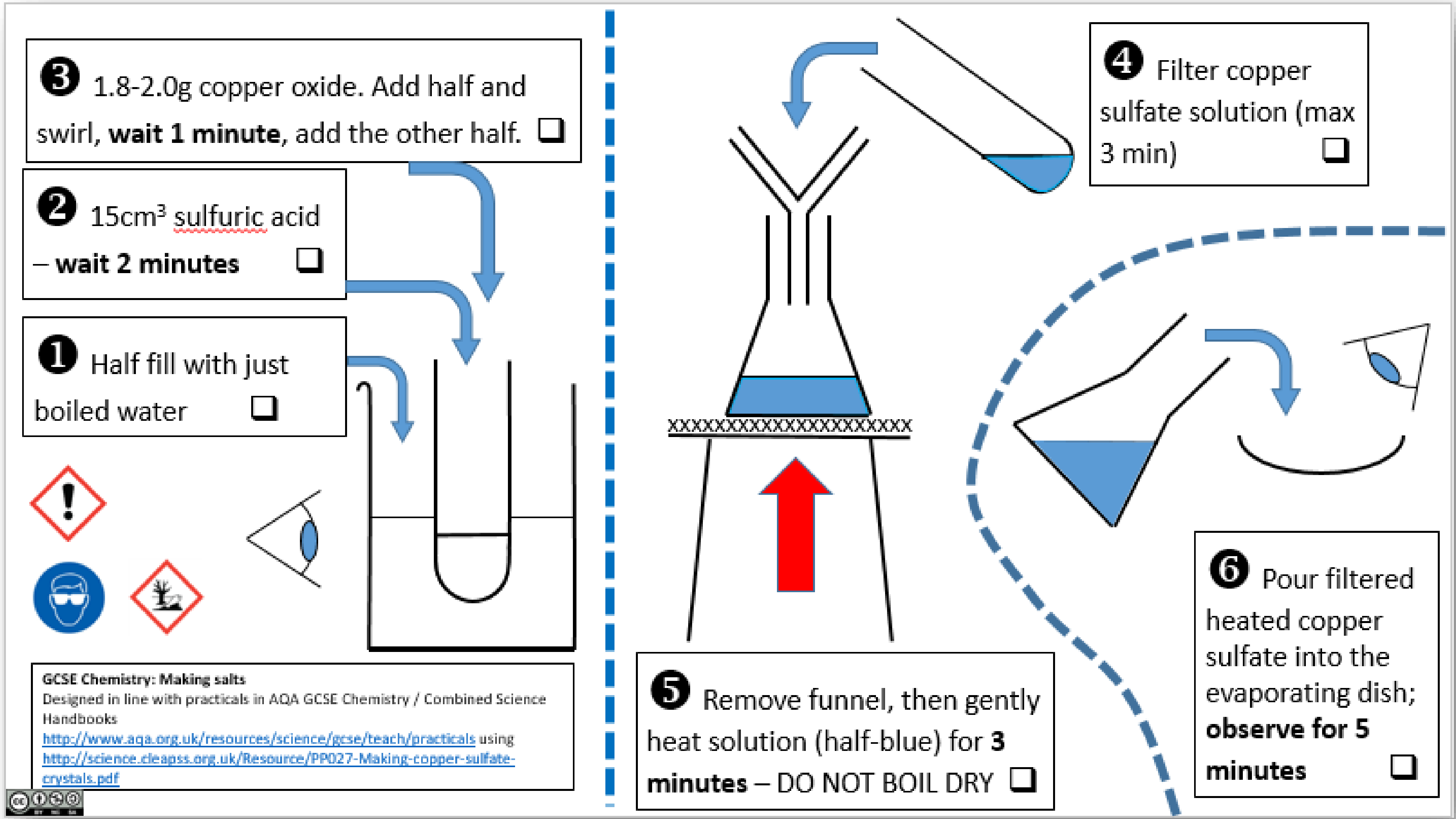


a Add 20 cm3 of the 0.5 M sulfuric acid to the 100 cm3 beaker. Heat carefully on the tripod with a gentle blue flame until nearly boiling.
b When the acid is hot enough (just before it starts to boil), use a spatula to add small portions of copper(II) oxide to the beaker. Stir the mixture gently for up to half a minute after each addition.
c When all the copper(II) oxide has been added, continue to heat gently for 1 to 2 minutes to ensure reaction is complete. Then turn out the Bunsen burner. It may be wise to check (using pH or litmus paper) that no acid remains. If the acid has not been hot enough, excess acid can co-exist with copper oxide.
d Allow the beaker to cool slightly while you set up Stage 2.
Stage 2
e Place the filter funnel in the neck of the conical flask.
f Fold the filter paper to fit the filter funnel, and put it in the funnel.
g Make sure the beaker is cool enough to hold at the top. The contents should still be hot.
h Gently swirl the contents to mix, and then pour into the filter paper in the funnel. Allow to filter through.
i A clear blue solution should collect in the flask. If the solution is not clear, and black powder remains in it, you will need to repeat the filtration.
Stage 3 (optional)
j Rinse the beaker, and pour the clear blue solution back into it. Label the beaker with your name(s). Leave the beaker in a warm place, where it won't be disturbed, for a week or so. This will enable most of the water to evaporate. would fill with toxic fumes.
k Before all the water has evaporated, you should find some crystals forming on the bottom of the beaker. Filter the solution. Collect the crystals from the filter paper onto a paper towel.

http://www.rsc.org/learn-chemistry/resource/res00001917/reacting-copper-ii-oxide-with-sulfuric-acid?cmpid=CMP00006703

Cook, M.P., 2006. Visual representations in science education: The influence of prior knowledge and cognitive load theory on instructional design principles. *Science education*, *90*(6), pp.1073-1091.

Integrated-instructions in practical work



Student practical work

Making integrated instructions

educationinchemistry

FEATURE

Improving practical work with integrated instructions

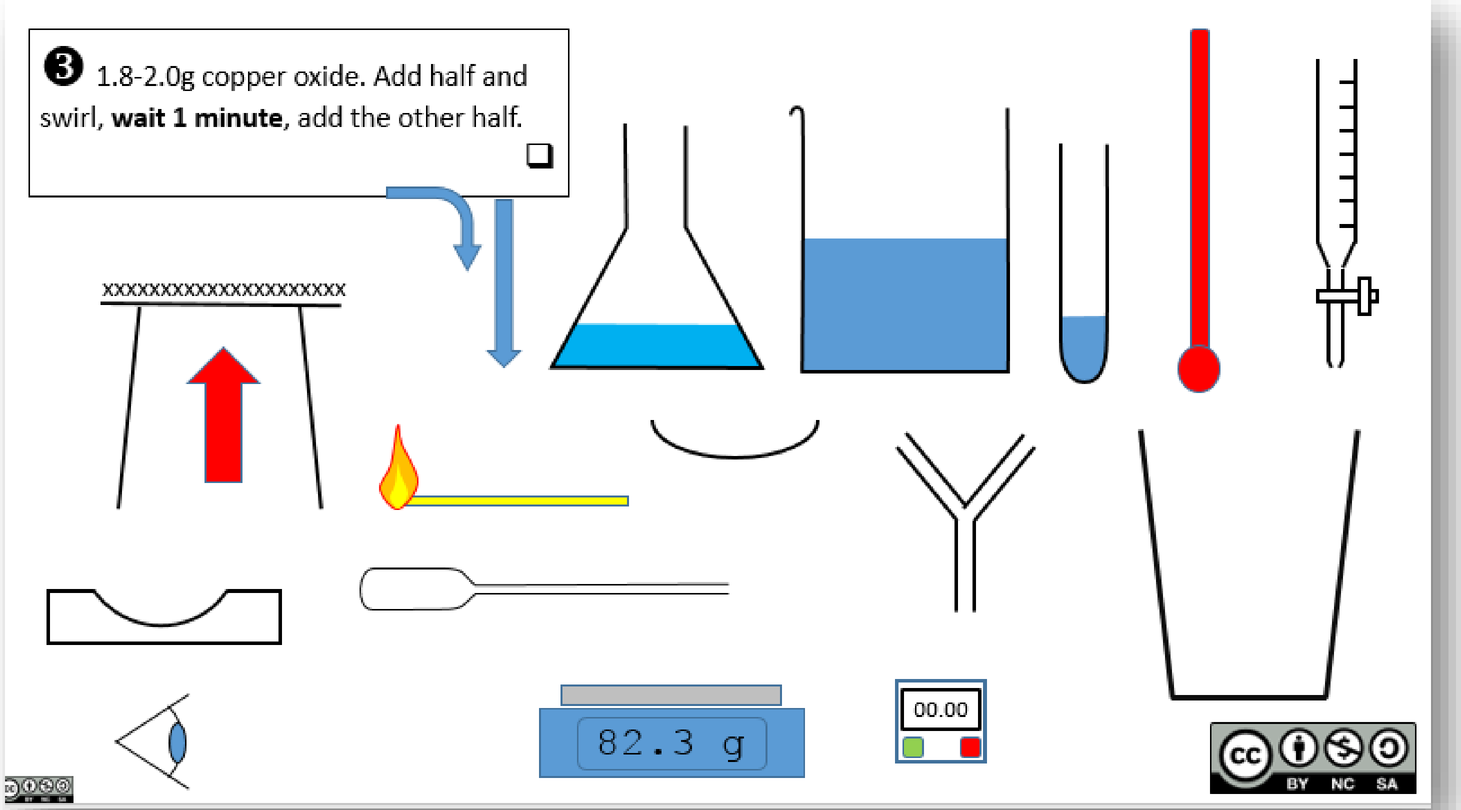
28 NOVEMBER 2018

Do your students struggle to follow written instructions?

https://eic.rsc.org/feature/improving-practical-work-with-integrated-instructions/3009798.article

EQUIPMENT	INSTRUCTIONS	FLOW	PICTOGRAMS	IN LESSON
Consider what the minimum required equipment is	Use clear numbering	Try to arrange instructions clockwise or anticlockwise	Use of 'eyes' to direct observation	Project the diagram on screen
	Minimum text necessary		Use of 'clocks' to indicate timings	Issue paper copies to all students
	Use of arrows to direct movement			
	Use tick boxes so students can track their progress			

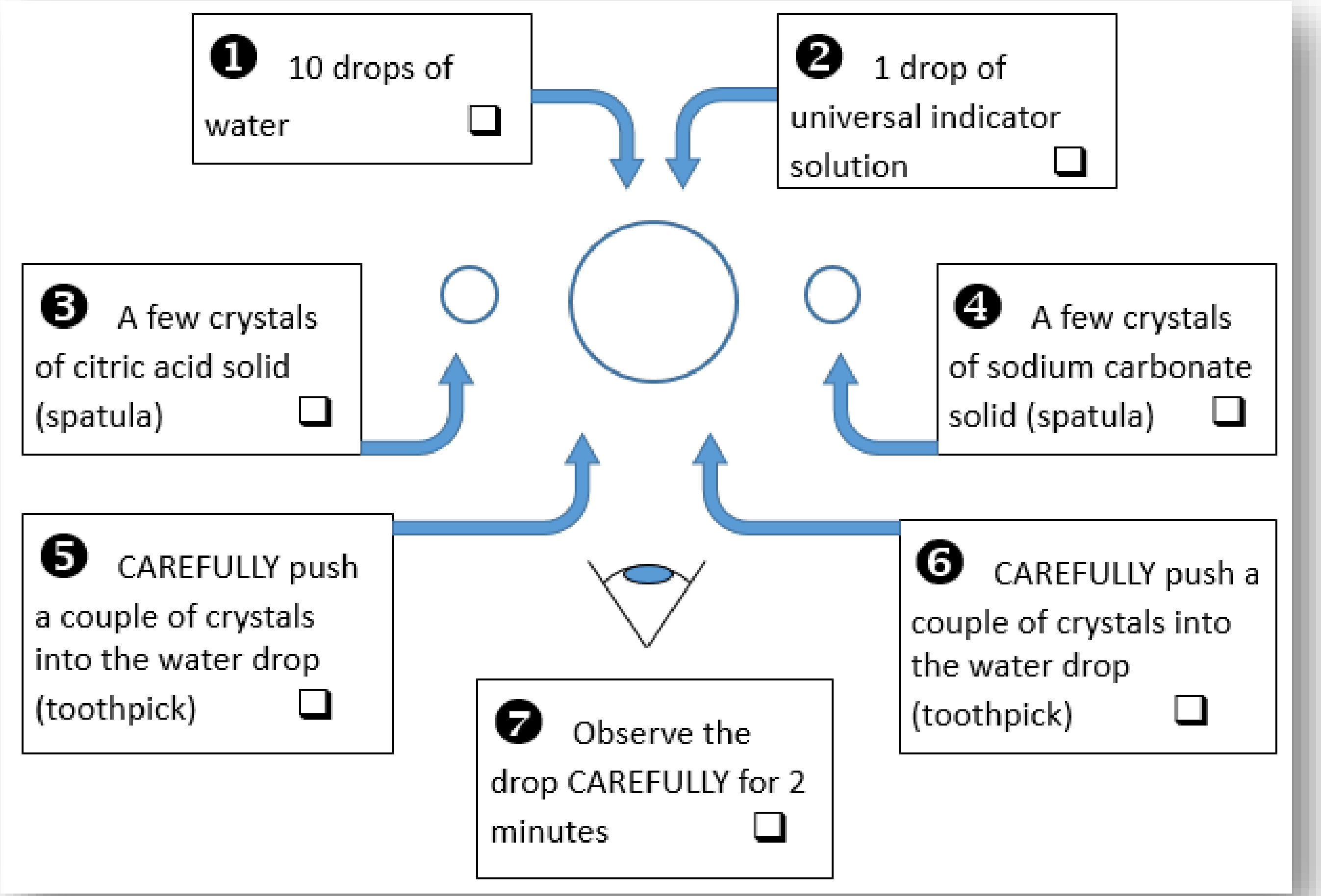
Making integrated instructions



chemix.org is also proving popular.

https://dave2004b.wordpress.com/2018/02/25/integrated-instructions-templates/

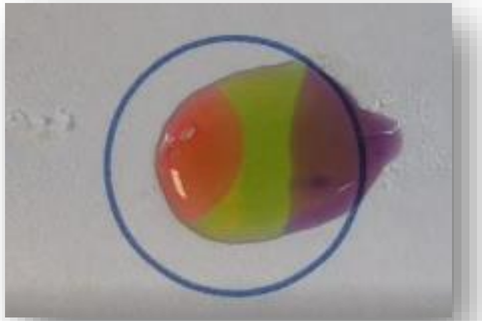
Microscale neutralisation



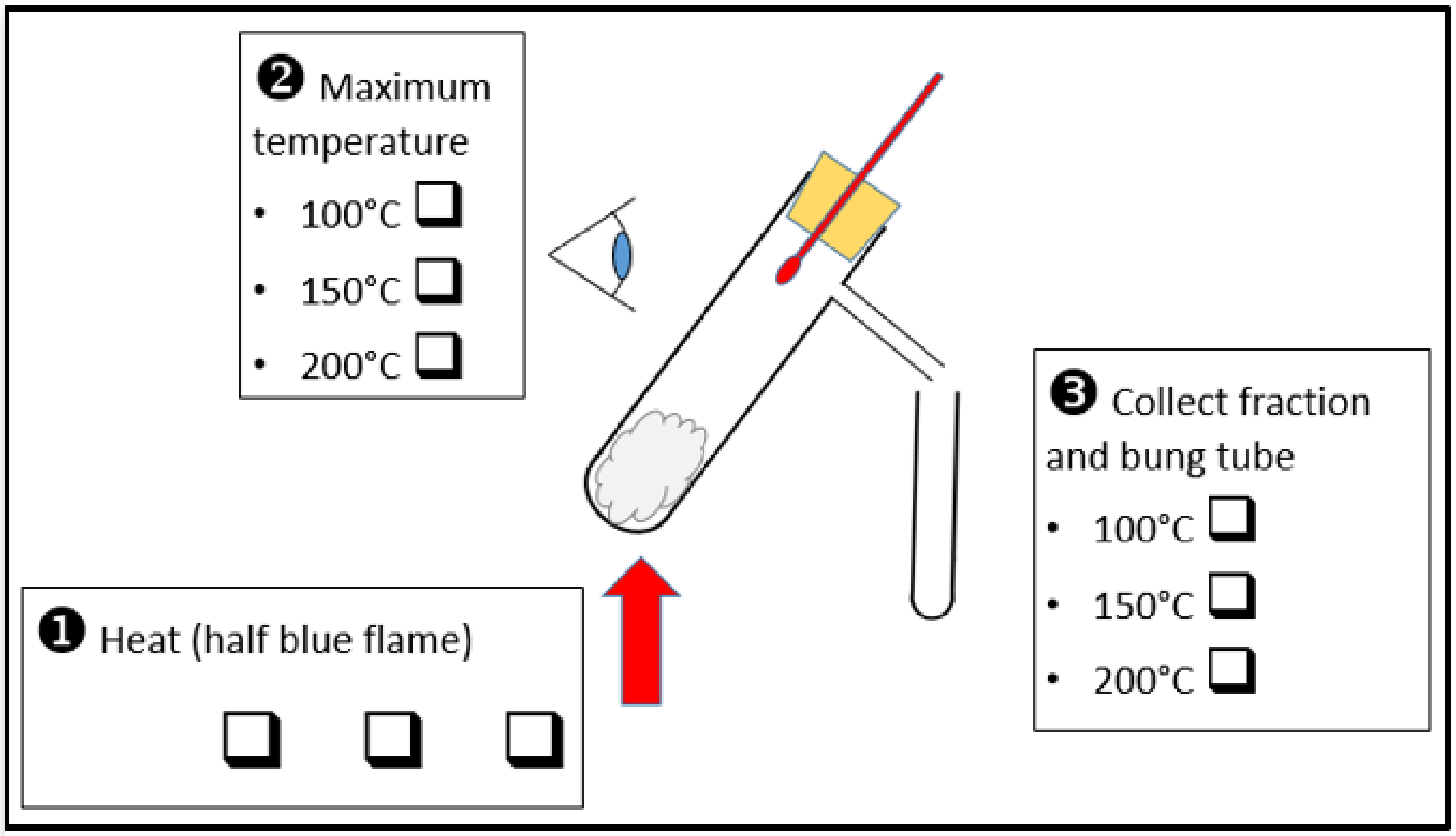
https://www.youtube.com/watch?v=qDeqKkSK3xI&t

Questions:

- ❑ Describe the sequence of observations – what happened first, second etc.
- ❑ What observations did you make that solutions were formed?
- ❑ What observations did you make that showed a neutralisation has occurred?



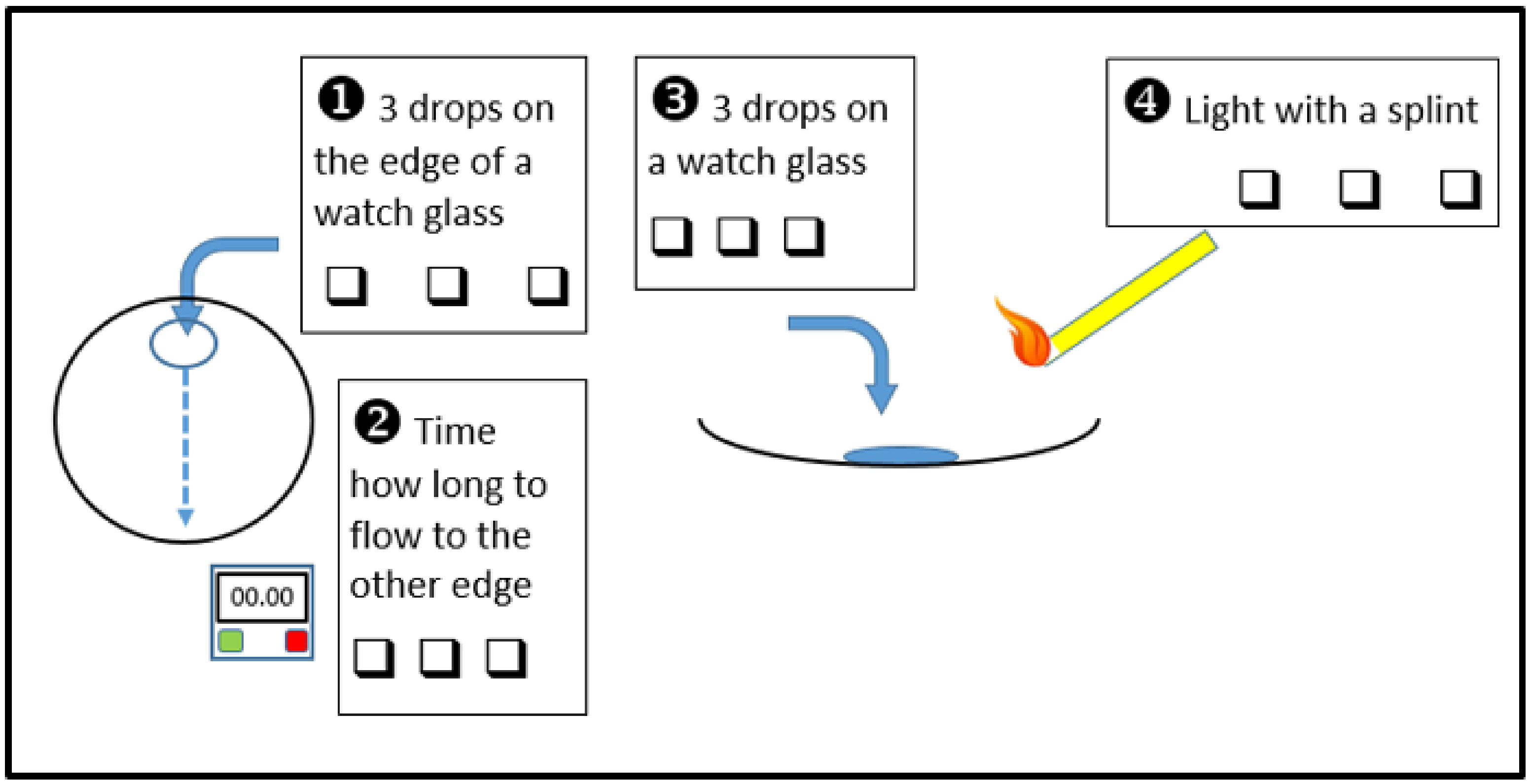
Distillation of crude oil



Questions:

- ❑ Describe the change in temperature you observed as you heated the crude oil.
- ❑ What observations did you make that showed distillation was occurring?
- ❑ What was the purpose of the tube between the **boiling tube** and **the collection test tube**?

Properties of crude oil fractions



Questions:

- Describe how the viscosity changed between the fractions.
- Describe how the ease of setting light to the fractions changed between the fractions.
- Describe how the odour changed between the fractions.

Journal of Chemical Education article

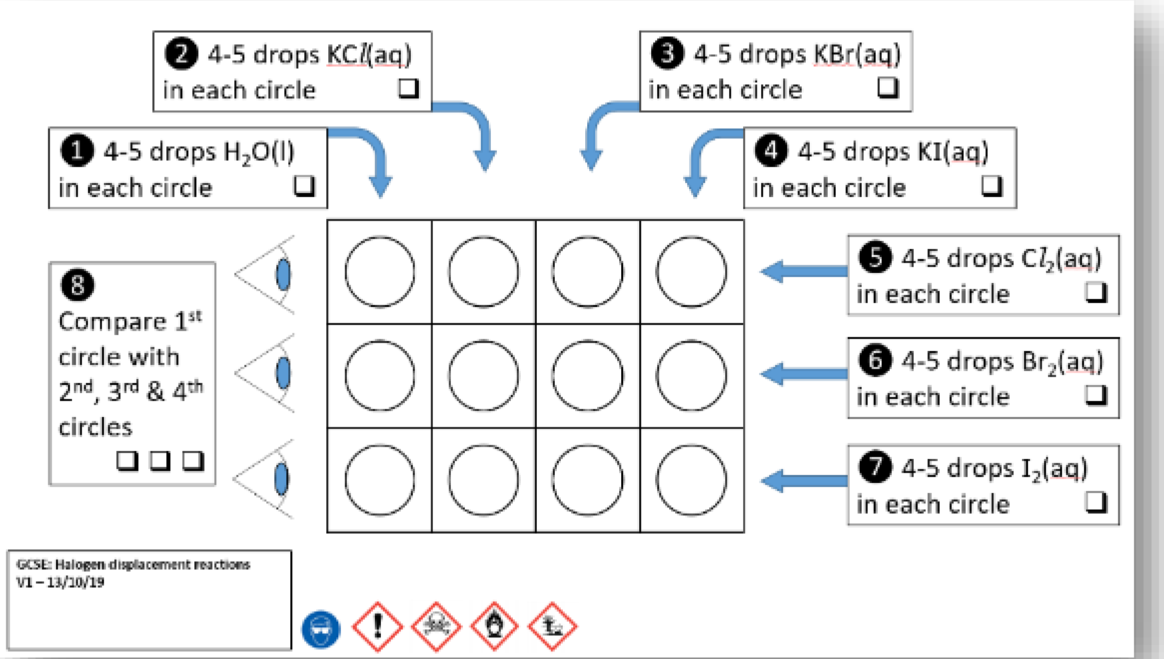
Design and Evaluation of Integrated Instructions in Secondary-Level Chemistry Practical Work

David J. Paterson*

Cite this: *J. Chem. Educ.* 2019, 96, 11, 2510–2517
Publication Date: October 18, 2019
https://doi.org/10.1021/acs.jchemed.9b00194

SUBJECTS: Teaching and learning methods, Anions,

Year 9: Traditional vs Integrated



PRACTICAL : Catalysis of the reaction between zinc and sulfuric acid

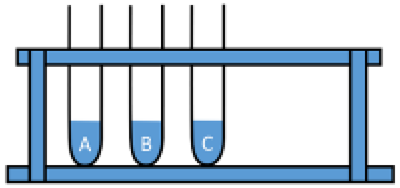
Purpose: To compare the rate of reaction of zinc with sulfuric acid in the absence and presence of catalysts.

Safety: Wear eye protection; tie back long hair

Equipment:

- test tubes (3)
- test tube rack
- measuring cylinder ($10 cm^3$)
- dropping pipette
- spatula
- granulated zinc (a few pieces)
- copper turnings (a few pieces)
- sulfuric acid, 1M (IRRITANT) ($15 cm^3$)
- copper(II) sulfuate(VI) solution, 0.5M (a few cm^3)
- marker pen

Diagram

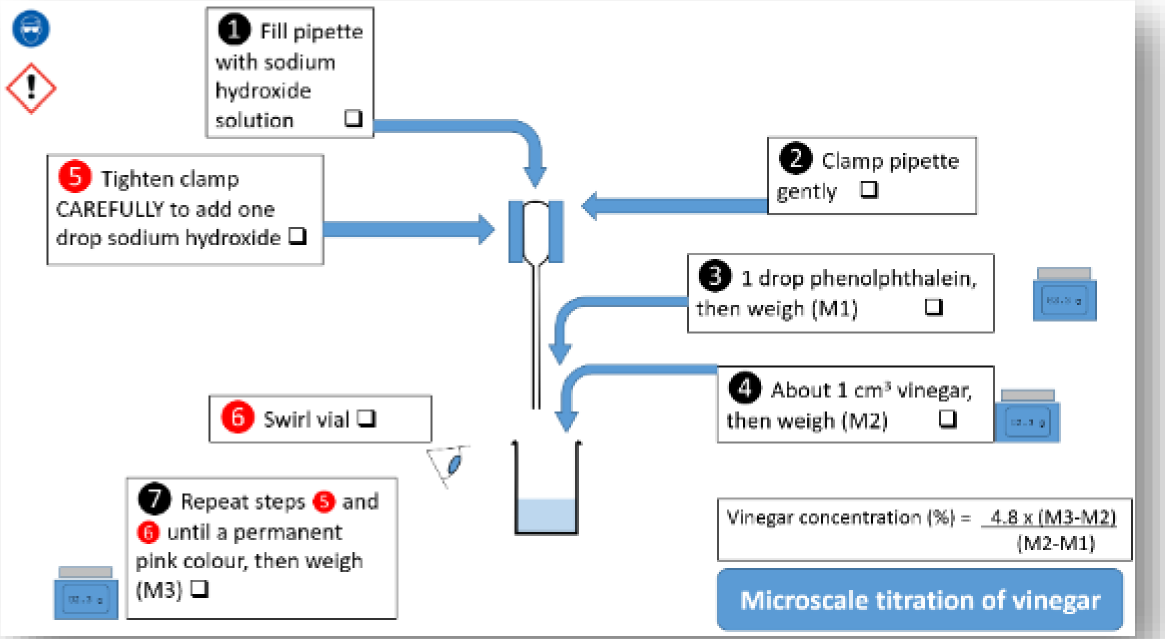


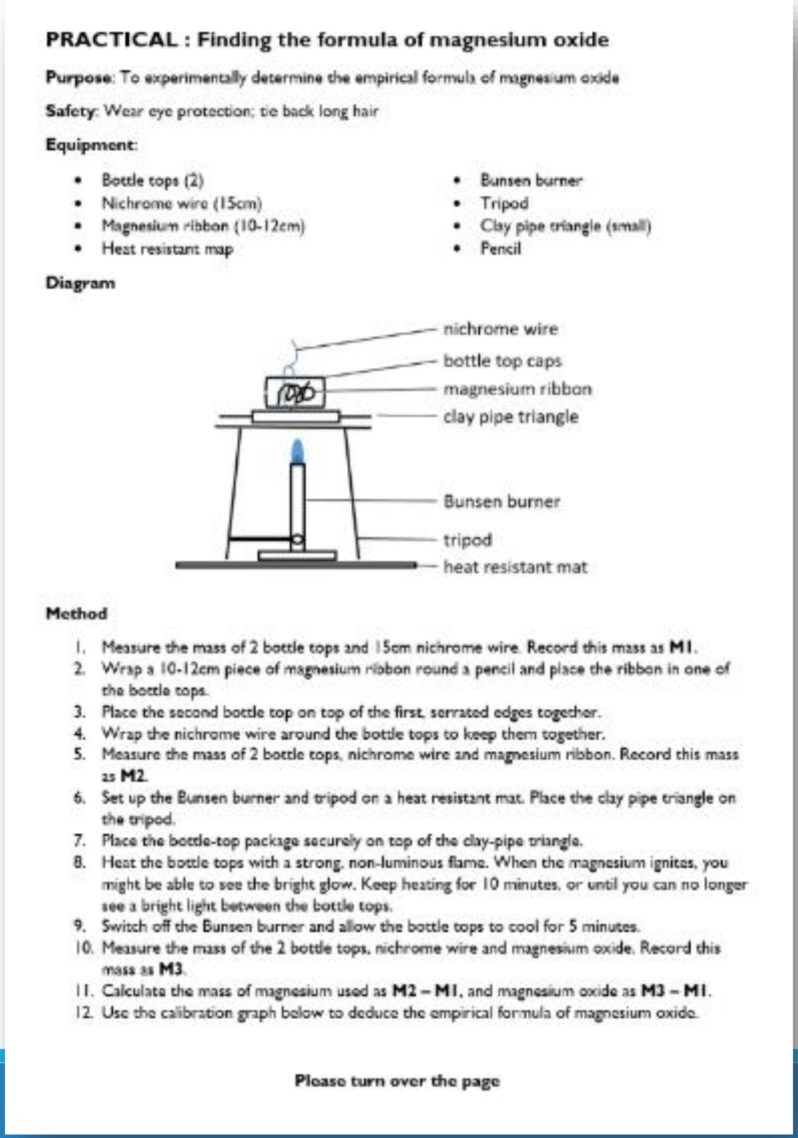
Method

1. Label three test tubes A, B, C
2. Add a few pieces of granulated zinc into each of the test tubes – try to have the same amount in each tube.
3. Add $5 cm^3$ of sulfuric acid to test tube A using a measuring cylinder.
4. Observe and estimate the rate (speed) of production of gas bubbles – note this in your table.
5. Add a few copper turnings to test tube B using a spatula, making sure they are in contact with the zinc.
6. Add $5 cm^3$ of sulfuric acid to test tube B using a measuring cylinder.
7. Observe and estimate the rate (speed) of production of gas bubbles – note this in your table.
8. Add $5 cm^3$ of sulfuric acid to test tube C using a measuring cylinder.
9. Add about $1 cm^3$ of copper sulfate solution to test tube C using a dropping pipette.
10. Observe and estimate the rate (speed) of production of gas bubbles – note this in your table.
11. Observe and note what happens to the colour of the solution and the surface of the zinc in test tube C over 1-2 minutes.

Please turn over the page

Year 12: Traditional vs Integrated





PRACTICAL : Finding the formula of magnesium oxide

Purpose: To experimentally determine the empirical formula of magnesium oxide

Safety: Wear eye protection; tie back long hair

Equipment:

- Bottle tops (2)
- Nichrome wire (15cm)
- Magnesium ribbon (10-12cm)
- Heat resistant map
- Bunsen burner
- Tripod
- Clay pipe triangle (small)
- Pencil

Diagram

nichrome wire
bottle top caps
magnesium ribbon
clay pipe triangle
Bunsen burner
tripod
heat resistant mat

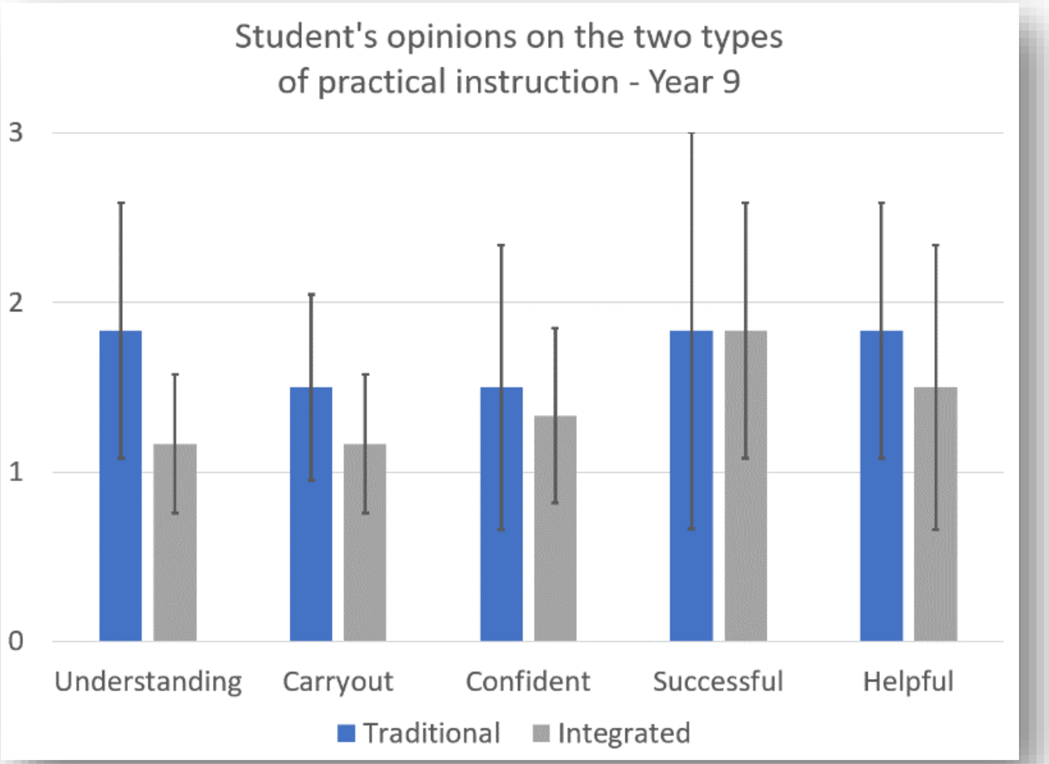
Method

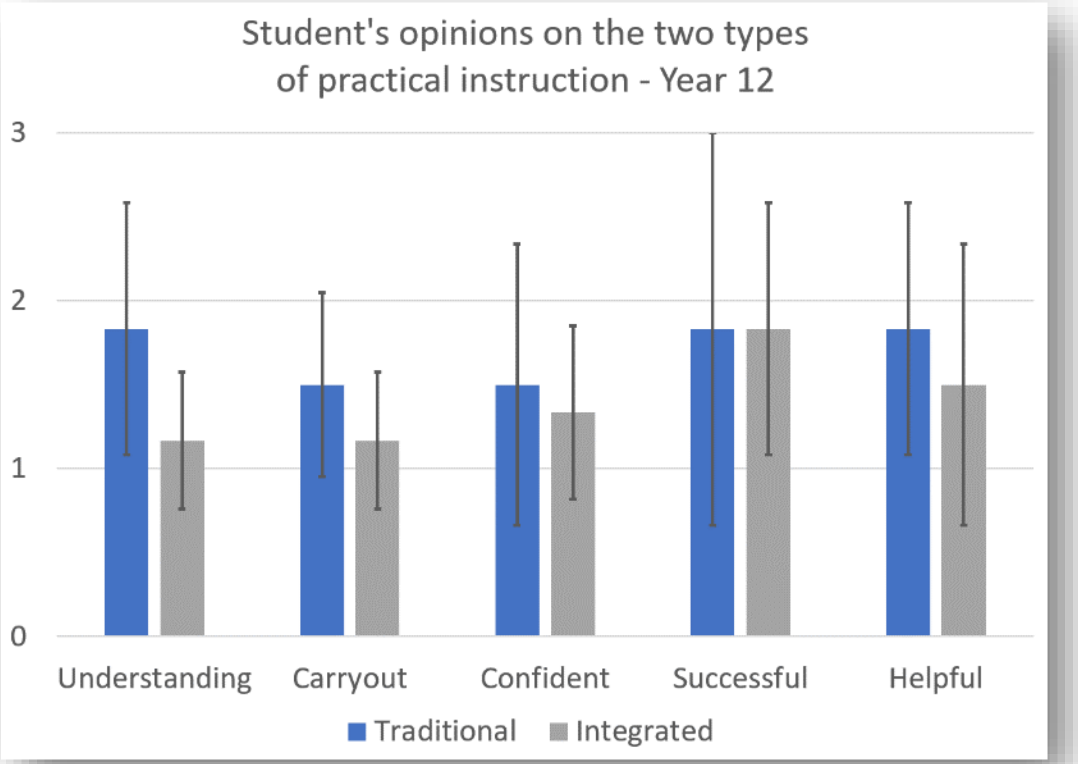
1. Measure the mass of 2 bottle tops and 15cm nichrome wire. Record this mass as **M1**.
2. Wrap a 10-12cm piece of magnesium ribbon round a pencil and place the ribbon in one of the bottle tops.
3. Place the second bottle top on top of the first, serrated edges together.
4. Wrap the nichrome wire around the bottle tops to keep them together.
5. Measure the mass of 2 bottle tops, nichrome wire and magnesium ribbon. Record this mass as **M2**.
6. Set up the Bunsen burner and tripod on a heat resistant mat. Place the clay pipe triangle on the tripod.
7. Place the bottle-top package securely on top of the clay-pipe triangle.
8. Heat the bottle tops with a strong, non-luminous flame. When the magnesium ignites, you might be able to see the bright glow. Keep heating for 10 minutes, or until you can no longer see a bright light between the bottle tops.
9. Switch off the Bunsen burner and allow the bottle tops to cool for 5 minutes.
10. Measure the mass of the 2 bottle tops, nichrome wire and magnesium oxide. Record this mass as **M3**.
11. Calculate the mass of magnesium used as **M2 – M1**, and magnesium oxide as **M3 – M1**.
12. Use the calibration graph below to deduce the empirical formula of magnesium oxide.

Please turn over the page

Student opinions of different practical types

lower is better





Understanding – How easy/hard did you find it to understand the practical instructions?
Carryout – How easy/hard did you find it to carry out the practical work?
Confident – How confident did you feel during the practical work?
Successful – How successful did you feel at the end of the practical?
Helpful – How helpful was the practical in your learning?

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